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# A study to evaluate optimal plan through different photon energies and their combination in oesophageal intensity modulated radiotherapy

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► ***Original article***

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## ABSTRACT

***Background*:** The primary goal of this research is to identify the best energy or energy combination for an Intensity Modulated Radiotherapy (IMRT) treatment plan of esophageal cancer. ***Materials and Methods*:** Ten retrospective oesophagus case patients were selected, treated with 6MV IMRT plans and later replanned with different energies and energy combinations. The same prescription, planning parameters and optimization constraints were applied to all plans which were analysed and compared based on certain plan parameters and dosimetric parameters. Comparisons were also made using technical specifications, such as Monitor Units (MUs) and Treatment Time (TT). ***Results*:** The study shows most significant results with (6X+10X) plan. The Planning Target Volume (PTV) mean dose, $D_{2\%}$, $D_{98\%}$, $D_{50\%}$ and Conformity Index ($CI_{95\%}$) improved as 29.68±0.38, 30.86±0.38, 27.42±0.67, 29.84±0.39 and 1.103±0.08 from their respective base plan values with the p-values 0.068, 0.176, 0.006, 0.159 and 0.085 respectively. Among Organs at risks (OARs), the right lung $V_{20}$, left lung $V_{20}$, spine mean dose and spine $D_{1\%}$ values reduced to 7.99±6.0, 10.59±7.7, 19.99±9.7 and 18.63±9.4 from 8.70±6.50, 11.98±7.9, 22.76±7.6 and 20.04+8.0 respectively with the p-values 0.172, 0.259, 0.090 and 0.092. Total MU and TT in the original plan were 5054.28±2286.1, and 25.12±11.2, however they were lowered to 3036.54±1556.2, and 16.52±11.2, with p-values of 0.043 and 0.137, respectively. ***Conclusion*:** This study concludes that the mixed energy plan (6X+10X) is optimal for high-quality IMRT therapy because of its superior dosimetric indices (i.e., PTV coverage, OAR doses, and technical factors like MUs, TT, and low photoneutron generation).

## INTRODUCTION

Radiotherapy aims to provide a lethal dose to the area affected while sparing healthy tissue. To achieve this, Intensity Modulated Radiotherapy (IMRT) may be used, which is preferable to the more common Three-Dimensional Conformal Radiation Therapy (3DCRT) when dealing with large volumes of deeply embedded tumors requiring high doses of radiation (>10MV) [1]. Weng *et al.* examined the dose distributions and the Dose Volume Histogram (DVH) for 3DCRT plan with 6 and 15 MV for lung cancer patients using the Monte Carlo method [2]. On the other hand, the potential for neutron creation must be taken into account.

IMRT will produce conformal dose distributions based on the fluence maps optimized and created by the Treatment Planning System (TPS) if the dose distributions are constrained by dose and dose-volume limits of the target and critical organs [1, 3-4]. With IMRT, the therapeutic ratio is improved because the PTV is more accurately irradiated and the OARs are protected to the greatest extent possible. Howell et al. evaluated the effective doses from beam delivery at various energies, including 6, 15, and 18 MV, and they discovered that the effective dose was lower with the conventional plans [5]. The amount of energy required by IMRT plans for efficient dose delivery is another key issue. Due to their limited capacity to penetrate, low-energy photon beams (6 MV) have been utilized to treat superficial tumors that are situated within a shorter depth. Despite the large doses that are delivered to the regions immediately around the beam entry points, a research discovered that the short penumbra of low-energy beams resulted in tighter dose distribution curves around the target, minimizing irradiation of neighboring vital organs [6]. Due to their greater penetrating power, skin-sparing effect, conformity on target volume, and lower dose to normal tissues, high-energy photon beams have been shown to be effective in treating deep-seated



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tumors; however, concerns about radiation leakage and secondary malignancy still make photon quality an important parameter to take into account during IMRT planning [7]. Dose compliance and the absence of photoneutron emissions make lower energies favored for usage in IMRT. High treatment delivery time and increased peripheral dose are two negative outcomes of lesser energy. Treatment of deep-seated cancers with lower-energy photons is challenging, particularly for individuals of greater height, and studies have shown that using various gantry angles may significantly enhance the total dose [8, 9]. Similar conclusions were established by Hall et al. in their research [10], which found that 6 MV plans enhance the low dose irradiated volume and the total dose, both of which may contribute to carcinogenesis.

Depending on the beam angle, the penetration depth of the various beam routes in the treatment plan for a case of Ca oesophagus will vary significantly. The proximity of radiosensitive lung tissue and other OARs, such as the heart and spinal cord, makes radiotherapy treatment for oesophageal cancer very difficult. We also used a different approach compared to earlier research in this area by analysing how changing beam energies and energy combinations based on penetration depths affected the quality of IMRT treatment plans. Eldesoky *et al.* [11] may have skewed their findings by modifying the dose volume constraints more or less rigorous to accommodate for patient-specific variations in the structures of interest if the algorithm consistently fails to satisfy all the parameters. This was not the case in our investigation. Here, the number of beams, beam angles, and the relative priority of dose constraints were held constant throughout all the single-energy and mixed-energy plan that were compared. Our study is novel as it reveals an ideal IMRT plan for oesophagus cases with varying depths for the different gantry angles used in the plan.

## MATERIALS AND METHODS

Ten patients with esophageal cancer between the ages of 45 and 75 were selected for this study and given 6MV photons according to a dose prescription of 30 Gy in 10 segments. The research project was given the green light by the local ethics committee (EC/NEW/INST/2022/KL/0056 & ECR/301/Inst/KL/2013/RR-19). All of the patients were placed in a supine posture with their heads resting on a flat couch using a thermoplastic mould, and CT scans were performed using a Philips Trueflight scanner with a slice thickness of 2mm. Once the images were acquired, they were imported into Eclipse TPS version 15.06, where volume and OAR delineation could be performed in accordance with the protocol. The International Commission on Radiation Units and Measurements (ICRU) 50 and 62 were used to delineate the contours of the tumor volumes, which were then overlaid with the OAR volumes. Another definition of "healthy tissue" is the portion of the patient's CT scan that is outside the PTV.

Figure 1 depicts the (1) axial, (2) beam's eye view, (3) frontal, and (4) sagittal plane dose distribution for a patient plan.

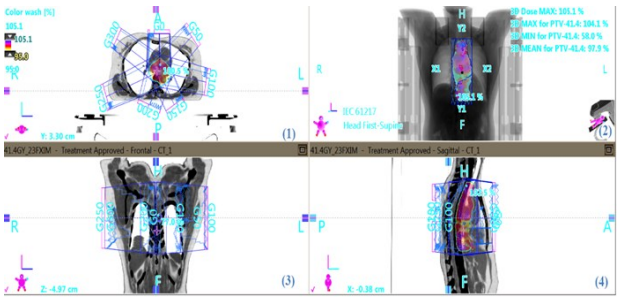

**Figure 1.** Dose profiles in **(1)** axial, **(2)** beam's eye view, **(3)** frontal, and **(4)** sagittal plane for a single patient.

The average AP distance was 18.72 cm (SD: 1.6; range 16-20cm), whereas the average lateral distance was 33.88 cm (SD 2.90; range 30-37 cm). These patients had a PTV volume of 570.55cc on average (range 121-1165cc, SD 379.9). Seven beams, separated by 50 degrees, were included into each IMRT treatment plan for a Varian Truebeam STx. Utilizing the jaw tracking method and the Anisotropic Analytical Algorithm, (AAA) we have determined the dose for IMRT using a 2.5 mm grid and a 120 leaf HD MLC. The MLC leaf sequence was generated using the leaf motion calculator of Smart LMC (15.6.05) to ensure that the fluence map was supplied at a consistent dose rate of 400 MU/min following IMRT optimization with an automatic normal tissue objective (NTO). Every PTV member was required to get at least 95% of the recommended dose, with no region receiving more than 107%. As per the RTOG protocol, the dose restrictions for the various OARs defined were maintained as low as feasible relative to their tolerance levels. After verifying the patient setup, the plan was accepted for treatment based on qualitative and quantitative analyses of tumor coverage and OAR doses, respectively.

In order to determine the optimal energy or energy mixture to produce an ideal plan that has exact dose delivery consistence to PTV and saves OARs to the maximum potential, we replicated and replanned these retrospective plans with different energies like 10 MV, 15 MV, 6FFF, 10FFF, and combinations of these energies. The energies for each beam in plans with energy combinations were determined by the penetration depths, with the lower energy of the two energies chosen for fields that penetrated less deeply to the PTV isocentre and the higher energy of the two energies chosen for fields that penetrated extra deeply to the PTV isocentre. For the sake of consistency and to facilitate a fair comparison, all plans were produced using the same prescription and with all other planning factors



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(beam angles, beam numbers, etc.) kept at the same value (with the exception of beam energy). Furthermore, all the plans were optimized using the same constraints in order to attain the same clinical goals. Our research stands out from the pack because it is the first of its kind to account for every potential energy and energy combination within the same treatment plan, as well as to include technical characteristics like total Monitor Units (MUs) and Treatment Time (TT).

All alternative plans were compared to the approved and irradiated one in terms of DVH, tumor coverage, OAR doses, and technical aspects, with the approved and irradiated one serving as the reference. Numerous dosimetric measures were used to assess the plans, including the Homogeneity Index (HI), Conformity Index (CI), Conformity Number (CN), Coverage Index (COVI), and Dose Gradient Index (DGI) [12].

According to the RTOG's proposed metrics for assessing treatment plan quality, higher HI and CI values indicate greater consistency. Dose homogeneity in a PTV, according to a research, guarantees the plan's sufficiency and adoption [13]. The dose homogeneity within the PTV is measured by HI, which has a desirable value of zero, as shown in equation (1).

$$HI = (D_{2\%} - D_{98\%}) / D50_{\%} \quad (1)$$

Doses received by 2%, 98%, and 50% of PTV volumes are denoted by $D_{2\%}$, $D_{98\%}$, and $D_{50\%}$ accordingly. The parameter CI at a certain isodose level 95% ($CI_{95\%}$) is used to evaluate the conformity of high dose around the target and its ideal value is illustrated in equation (2):

$$CI_{95\%} = \text{Volume within 95\% isodose line/Volume of PTV} \quad (2)$$

Since the CN accounts for both the target volume and the surrounding healthy tissues, it may be used as a measure of dose conformance to target. Equation (3) depicts the CN, whose ideal value is 1.

$$CN_{95\%} = (TVpi /TV) \times [TVpi/Vpi] \quad (3)$$

The tumour volume, denoted by TV, the volume containing 95% of the prescribed isodose, denoted by Vpi, and the volume of interest within Vpi, denoted by TVpi, in equation (3).

Noted and computed is the COVI in equation (4); whose ideal value is 1:

$$COVI = TVpi/ TV \quad (4)$$

The gradient measure, which is the difference in centimeters between the corresponding sphere radii of the prescribed isodose and the half prescribing isodose, may be used to visualise dose gradients around a target. The dose gradients around the target increase as the gradient measure lowers. Assuming a perfect DGI of 1, one would use the equation (5);

$$DGI = PI/D_{50\%} \quad (5)$$

Where PI is the prescribed isodose volume and D50% is the volume equal to 50% of the isodose volume.

It was also possible to compare the plans by examining at their mean dose, $D_{2\%}$, $D_{98\%}$, and $D_{50\%}$ values for the PTV. Maximum dose, average dose, and precise values of volume receiving xGy have all been recorded in the established OARs. The mean dose, V5 and V30 values are provided when discussing healthy tissue, where V5 is the volume getting 5 Gy and V30 is the volume receiving 20 Gy.

### *Statistical analysis*

Information was analysed using SPSS 26.0, a statistical program designed for the social sciences. The data were checked for normalcy using the Shapiro-Wilk test. Continuous data were shown using means and standard deviations. The statistical significance of the correlations and discorrelations between the pairings was assessed using the paired t test. A p-value of 0.05 or less indicates statistical significance [14].

All patients' total treatment time (TT) and total Monitor units (MUs) were recorded and compared.

## RESULTS

DVH was used as a plan evaluation tool to compare the doses and dosimetric parameters of different plans under study. Figure 2 displays the Dose Volume Histogram analysis of base plan along with all other plans compared for a given patient.

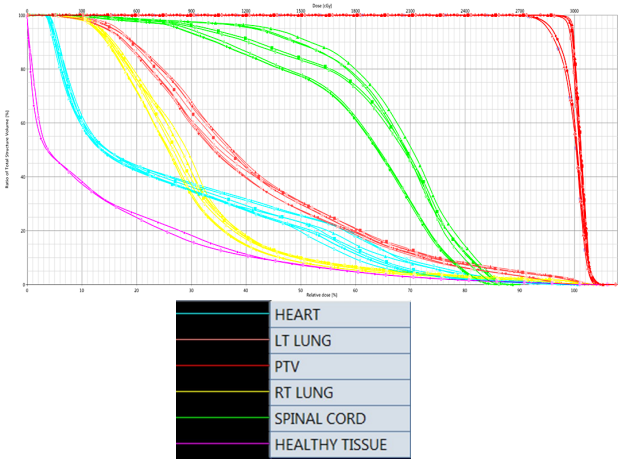


**Figure 2.** The DVH comparison of all plans for a single patient.

The dosimetric and technical parameters evaluated between the treatment base plan 6X and all other energy/energy combination plans are tabulated in table 1, 2 and 3. The study shows most significant results with (6X+10X) plan in overall plan quality. The PTV mean dose, D2%, D98%, D50% and CI95% improved as 29.68±0.38, 30.86±0.38, 27.42±0.67,



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29.84±0.39 and 1.103±0.08 from their base plan values to 30.14±0.17, 31.15±0.11, 28.53±0.90, 30.2±0.14 and 1.257±0.14 respectively with the significant P values 0.006 and 0.009 for D98% and HI 95%. Among OARs, the heart mean dose, right lung V20, left lung V20, left lung mean dose, spine mean dose and spine D1% value reduced to 9.95±4.3, 7.99±6.0, 10.59±7.7, 10.00±1.8, 19.99±9.7 and 18.63±9.4 from 10.05±4.7, 8.70±6.50, 11.98±7.9, 10.13±2.4, 22.76±7.6 and 20.04+8.0 respectively. The base plan total MU and TT value of 5054.28±2286.1 and 25.12±11.2 reduced to 3036.54±1556.2 and 16.52±11.2 respectively with a P value of 0.043 for total MUs.

The mean, standard deviation, and P values for the parameters analysed from the Dose Volume Histogram of the Planning Target Volume, the Organs at Risk, and the Technical Characteristics are shown in tables 1, 2, and 3, respectively.

**Table 1.** Dosimetric indices of Planning Target Volume for plans of different energies and energy combinations.

| | | | | | | | | | P VALUE | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PARAMETER | 6X | 10X | 15X | 6FFF | 10FFF | 6X+10X | 6X+15X | 10X+15X | 10X vs 6X | 15X vs 6X | 6FFF vs 6X | 10FFF vs 6X | (6X+10X) vs 6X | (6X+15X) vs 6X | (10X+15X) vs 6X |
| MeanDose | 30.14±0.17 | 30.30±0.21 | 30.30±0.11 | 30.34±0.16 | 30.38±0.08 | 29.68±0.38 | 29.86±0.36 | 29.56±0.35 | 0.179 | 0.029 | 0.202 | 0.025 | 0.068 | 0.227 | 0.023 |
| D2% | 31.15±0.11 | 31.14±0.19 | 31.10±0.15 | 31.20±0.32 | 31.26±0.17 | 30.86±0.38 | 31.05±0.32 | 30.75±0.38 | 0.935 | 0.247 | 0.654 | 0.089 | 0.176 | 0.483 | 0.100 |
| D98% | 28.53±0.90 | 29.27±0.49 | 29.13±0.75 | 29.17±0.55 | 29.27±0.51 | 27.42±0.67 | 27.99±0.99 | 27.36±0.64 | 0.140 | 0.006 | 0.066 | 0.031 | 0.006 | 0.337 | 0.008 |
| D50% | 30.2±0.14 | 30.33±0.20 | 30.32±0.11 | 30.36±0.14 | 30.39±0.11 | 29.84±0.39 | 29.95±0.29 | 29.72±0.34 | 0.165 | 0.036 | 0.230 | 0.012 | 0.159 | 0.205 | 0.053 |
| CI95% | 1.257±0.14 | 1.301±0.12 | 1.291±0.11 | 1.306±0.12 | 1.150±0.25 | 1.103±0.08 | 1.158±0.10 | 1.041±0.08 | 0.262 | 0.066 | 0.075 | 0.559 | 0.085 | 0.219 | 0.044 |
| HI95% | 0.087±0.03 | 0.062±0.02 | 0.065±0.03 | 0.067±0.02 | 0.085±0.04 | 0.115±0.02 | 0.102±0.03 | 0.114±0.02 | 0.077 | 0.005 | 0.032 | 0.914 | 0.009 | 0.372 | 0.021 |
| CN95% | 0.739±0.07 | 0.740±0.06 | 0.742±0.06 | 0.742±0.06 | 0.731±0.08 | 0.720±0.09 | 0.745±0.07 | 0.722±0.09 | 0.914 | 0.778 | 0.796 | 0.637 | 0.480 | 0.851 | 0.509 |
| COV I | 0.961±0.05 | 0.977±0.04 | 0.977±0.03 | 0.981±0.02 | 0.915±0.15 | 0.946±0.03 | 0.927±0.05 | 0.866±0.08 | 0.118 | 0.164 | 0.196 | 0.560 | 0.281 | 0.321 | 0.049 |
| DGI | 0.285±0.08 | 0.532±0.54 | 0.292±0.07 | 0.291±0.08 | 0.250±0.13 | 0.257±0.08 | 0.262±0.07 | 0.246±0.07 | 0.357 | 0.113 | 0.055 | 0.517 | 0.200 | 0.250 | 0.112 |

CI95% - Conformity Index, HI95% - Homogenity Index, CN95% - Conformation Number, COV I – Coverage Index, DGI – Dose Gradient Index.

**Table 2.** Dosimetric indices of Organ at Risks for plans of different energies and energy combinations.

| | | | | | | | | | | P VALUE | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PARAMETER | | 6X | 10X | 15X | 6FFF | 10FFF | 6X+10X | 6X+15X | 10X+15X | 10X vs 6X | 15X vs 6X | 6FFF vs 6X | 10FFF vs 6X | (6X+10X) vs 6X | (6X+15X) vs 6X | (10X+15X) vs 6X |
| HEART | MeanDose | 10.05±4.7 | 10.19±4.3 | 10.15±4.2 | 10.48±4.4 | 10.30±4.3 | 9.95±4.3 | 10.21±4.1 | 10.16±3.6 | 0.541 | 0.703 | 0.059 | 0.291 | 0.617 | 0.610 | 0.847 |
| | V25 | 6.69±3.9 | 8.05±3.9 | 7.32±3.3 | 7.59±3.9 | 7.67±3.4 | 9.60±6.0 | 8.65±4.9 | 8.32±4.50 | 0.294 | 0.127 | 0.010 | 0.033 | 0.156 | 0.210 | 0.363 |
| RT LUNG | Mean Dose | 7.94±3.2 | 8.73±2.4 | 8.74±2.2 | 8.66±2.2 | 8.64±2.1 | 8.42±1.2 | 8.10±1.9 | 8.65±1.3 | 0.212 | 0.228 | 0.270 | 0.283 | 0.728 | 0.836 | 0.589 |
| | V20 | 8.70±6.5 | 9.29±6.9 | 9.28±6.8 | 9.08±6.5 | 9.26±6.8 | 7.99±6.0 | 7.75±5.6 | 7.8±6.0 | 0.069 | 0.017 | 0.006 | 0.018 | 0.172 | 0.320 | 0.409 |
| LT LUNG | Mean Dose | 10.13±2.4 | 10.41±2.5 | 10.39±2.4 | 10.26±2.3 | 10.27±2.3 | 10.00±1.8 | 9.86±2.2 | 10.19±1.8 | 0.085 | 0.022 | 0.181 | 0.068 | 0.806 | 0.143 | 0.901 |
| | V20 | 11.98±7.9 | 13.09±8.1 | 12.62±8.3 | 11.87±7.7 | 12.37±7.9 | 10.59±7.7 | 10.32±8.1 | 10.30±7.7 | 0.092 | 0.084 | 0.699 | 0.316 | 0.259 | 0.140 | 0.222 |
| SPINE | Mean Dose | 22.76±7.6 | 22.49±7.4 | 22.48±7.5 | 23.78±8.4 | 22.58±7.7 | 19.99±9.7 | 21.42±6.7 | 19.83±9.7 | 0.526 | 0.617 | 0.234 | 0.588 | 0.090 | 0.158 | 0.094 |
| | D1% | 20.04±8.0 | 20.29±8.1 | 20.23±8.0 | 21.17±9.2 | 20.01±8.0 | 18.63±9.4 | 19.57±7.6 | 18.78±9.4 | 0.193 | 0.341 | 0.304 | 0.913 | 0.092 | 0.170 | 0.134 |
| HT | Mean Dose | 4.70±1.3 | 4.74±1.4 | 4.72±1.4 | 4.74±1.3 | 4.65±1.3 | 5.32±2.3 | 4.73±1.3 | 4.70±1.3 | 0.617 | 0.071 | 0.274 | 0.203 | 0.411 | 0.824 | 0.984 |
| | V5 | 30.59±9.7 | 31.20±10 | 31.21±9.5 | 30.69±9.7 | 30.61±9.4 | 32.76±11.5 | 32.02±9.5 | 32.07±9.4 | 0.238 | 0.045 | 0.768 | 0.934 | 0.342 | 0.294 | 0.245 |
| | V30 | 5.08±2.8 | 5.22±2.9 | 5.16±2.8 | 5.19±2.8 | 5.10±2.8 | 6.70±5.3 | 4.75±2.6 | 4.55±2.5 | 0.477 | 0.057 | 0.211 | 0.828 | 0.438 | 0.075 | 0.018 |

RT Lung- Right Lung, LT Lung- Left Lung, HT- Healthy Tissue

**Table 3.** Technical characteristics of plans with different energies and energy combinations.

| | | | | | | | | | P VALUE | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PARAMETER | 6X | 10X | 15X | 6FFF | 10FFF | 6X+10X | 6X+15X | 10X+15X | 10X vs 6X | 15X vs 6X | 6FFF vs 6X | 10FFF vs 6X | (6X+10X) vs 6X | (6X+15X) vs 6X | (10X+15X) vs 6X |
| MU | 5054.28±2286.1 | 5033.24±2428.3 | 4866.90±2276.2 | 6229.84±3219.5 | 7108.54±3776.9 | 3036.54±1556.2 | 3705.20±1573 | 2842.28±1431.1 | 0.864 | 0.036 | 0.064 | 0.042 | 0.043 | 0.206 | 0.049 |
| TT | 25.12±11.2 | 25.02±11.9 | 24.33±11.4 | 25.02±15.9 | 35.31±18.7 | 16.52±11.2 | 14.1±7.2 | 14.21±7.2 | 0.866 | 0.093 | 0.064 | 0.044 | 0.137 | 0.041 | 0.048 |

MU - Monitor Units, TT - Treatment Time

## DISCUSSION

The findings of our analysis demonstrate that, when compared to the base plan, all of the customized plans vary significantly in terms of all metrics, highlighting the need to use specific energy/energy combinations outside of the standard 6X energy plans for treatment. Many previous studies [15], including those that we cite, have concluded that the 6MV photon beam is the most effective energy option for most IMRT plans since it produces the fewest variations across plan energies. Another study [16] demonstrated that for deep target volumes, increasing the total number of fields rendered lower energy and higher energy plans equivalent in terms of all dosimetric features. However, when comparing the energy or energy combination plans we developed to the baseline plan, we found statistically significant improvements in the dosimetric characteristics of both the PTV and normal tissues.

Treatment duration, integral dose, and OAR doses increase with these lower-energy IMRT plans with a higher number of fields and MU, which is concerning because of the potential for adverse skin responses, especially in large patients with large tumour volumes located deep within the body [17]. For this reason, our research emphasizes the dosimetric impact of both high-energy and high-energy-



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combination sources. Our findings table makes it abundantly clear that, when compared to the 6X base plan, all of the dosimetric parameters of PTV examined have gained superior values in majority of the plans generated with greater energy and energy combinations. Our findings are supported by a research by Sung *et al.* [18], who evaluated the influence of various photon energies (6, 10, and 15 MV) on the treatment of prostate patients using IMRT plans and found that the plans using 10 MV yielded superior outcomes with lower total doses and more OAR sparing. The fundamental need for high energy in the plan is the need to provide a greater dose to a bulkier tumour volume; to achieve this, the photon beam's maximal dose must penetrate deeply into the larger tumour volume, which lowers the tumour volume to normal tissue interface volume ratio.

After comparing the findings of our research with technical data, we found that, with the exception of the 10FFF plan, all of the energy and energy combination plans we developed resulted in a considerable reduction in total MUs and TT when compared with the 6X plan. In support of this, a research found that the MUs in 6MV plans are 1.1 times greater than in 15MV plans, which is a disadvantage of the same [19]. Leakage radiation increases the risk of subsequent cancers, and this rise in total MUs is a cause for concern. According to a review of the literature [20], bigger patients or target volumes benefit more with energies 10MV when attempting to treat deep-seated abdominal or pelvic diseases. While considering IMRT with scanned photon beams, it is recommended, according to the research of Soderstrom *et al.* [21], that a very high energy photon be used, together with a thin target, to provide the narrowest possible bremsstrahlung lobe.

Since we included FFF energy plans in our analysis, we found that the dosimetric values for the PTV, OAR dose levels, and technical parameters were all much better than those found in previous studies. To sharpen the penumbra and avoid damaging the superficial tissues with high-energy photons, the radiation beam should have a concentrated area of high-intensity radiation in the centre and a more diffuse area of lower-intensity radiation at the edges. In this article, we'll speak about the neutron dose of flattening filter-free photons. Gudowska *et al.* [22] claim that when scanned photon beams are used in situations where a flattening filter is not required, the neutron production per unit photon dose is too low at high photon energies in the patient.

Our results show that plans with higher energy alone provide higher-quality plans based on their dosimetric properties, but these plans have certain limitations in terms of their clinical utility with respect to the neutron dose for patients. With IMRTs, the MLCs move constantly during treatment, necessitating more MUs and more beam-on time than with traditional radiation; nevertheless, high energy is always constrained by the possibility of increased photoneutron generation and dose to patients [23]. Our research suggests that treatment approaches including single, higher-energy photons are preferable, since they do not produce secondary neutrons, which add to unneeded exposure to the patient.

Our analysis here concentrates on mixed-energy plans, and such plans are shown to make use of both low- and high-energy beams, lending credence to our findings. As can be seen in table 2, the OAR parameters for all plans are displayed, and it is clear that the mixed energy plans provide better dosimetric values, with the exception of V25 of heart, mean dose of rt lung, and V5 of healthy tissue. When using mixed energy IMRT plans for deeply seated tumour volumes, the authors determined that decreasing the dose to the OARs would improve the overall plan quality [24], despite the fact that this reduction in dose is not clinically important. The results of our study show that mixed energy plans not only enhance plan quality but also decrease the dose to OARs, so this finding runs counter to those results. Mixed energy IMRT plans, which take advantage of the dosimetric characteristics of both low and high energy beams (low energy photons could provide tighter dose distributions around the target, while high energy photons give superior penetrating power), have been recommended by several studies for deeply seated tumors [24-25].

Table 3 of technical features has significant P values for (6X+10X) and (10X+15X) among total MUs and for (6X+15X) and (10X+15X) among total TTs, providing more specific information for MUs and TTs with mixed energy plans. According to Haneefa *et al.* [26], the mean MU is not significantly different between the 6MV plan and the mixed energy plan when computed using the Collapsed Cone Convolution (CCC) and Pencil Beam (PB) algorithms, despite the fact that fewer neutrons are recorded in the mixed energy plan compared to higher energy with greater dose conformity. Radiation-induced secondary cancer risks are reduced further with mixed energy plans since integral doses are reduced to 93% of that in 6MV plans.

This research proposes a mixed energy combination of (6X+10X) for high-quality IMRT after weighing the advantages and disadvantages of both lower and higher energies. According to our research, the (6X+10X) plan is superior than the (6X+15X) and (10X+15X) plans in terms of overall plan quality, despite all three plans displaying improved dosimetric values with substantial P values across the board for PTV coverage, OAR doses, and technical characteristics. This is supported by the fact that, as reported by Kry *et al.* [27], there is almost no neutron creation at 10 MV, and by the combined dosimetric properties of 6 and 10 MV.The plan with a combination of 6X and 10X energies will result in the lowest photo-neutron generation when compared to the other two plans with much greater energies



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(6X+15X and 10X+15X). Moreover, Soderstrom *et al.* [28] found that the optimal single accelerator potential for treating both superficial and deep tumor volumes was within the range of 6-15 MV. Considering these factors, our research suggests that 6X and 10X are the bare minimum in a linac configuration for effective IMRT therapy, particularly in the case of oesophageal cancer.

## CONCLUSION

Based on the study's findings, a mixed energy plan (6X+10X) is recommended as the best option for high -quality IMRT therapy because of its excellent PTV coverage, OAR dose, and technical factors including little photoneutron generation. It also recommends that centers equipped with linear accelerators of 6X and 10X energy so that patients may get effective IMRT.

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